

NAZ AHMED SHAIKH

GEOLOGY OF THE LAUTTAKOSKI  
SOAPSTONE DEPOSIT,  
NORTHERN SWEDEN

WITH ONE PLATE



STOCKHOLM 1972

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This paper is dedicated  
to  
Fritz Brotzen

## CONTENTS

	Page
Abstract .....	5
Introduction .....	5
General geology .....	5
Description of the country rocks .....	6
Quartzite .....	6
Crystalline limestone .....	6
Meta-argillite .....	7
Graphite-rich schist .....	9
Basic meta-volcanic rocks .....	10
Basic intrusive rocks .....	14
Albitites .....	17
The soapstone deposit .....	22
Mode of occurrence .....	23
Mineralogical and chemical composition .....	23
Discussion .....	27
Conclusions .....	31
Acknowledgements .....	31
References .....	32

### Abstract

The soapstone deposit near Lauttakoski is the largest known deposit in the Pre-Cambrian of Sweden. The present study shows that it is an alteration product of a more or less concordant ultramafic intrusion in the supracrustal rocks of the Veikkavaara Group. The ultramafic intrusion is somewhat older than associated basic intrusive rocks. The basic intrusive and to some extent even the basic meta-volcanic rocks are rich in sodium. Albitites are also present. The processes involved in the alteration of the ultramafic rock into soapstone are discussed.

### Introduction

The Lauttakoski soapstone deposit is located (lat.  $67^{\circ}24'N$ , long.  $22^{\circ}23'E$  Greenwich) c. 7 km south-west of the village of Junosuando in the Pajala district of Norrbotten County. The deposit, which has been known a long time (Fredholm 1886, Svenonius 1915), occurs along the eastern bank of the river Tärendö. Soapstone outcrops at few places in the northern part of the occurrence, the majority of which is covered with glacial till. The Geological Survey of Sweden (SGU) first undertook trenching, followed by a ground magnetic survey in 1967 and drilling, the operations being completed finally in 1969. Ten diamond drill-holes that total c. 950 m were drilled. The investigations were commissioned by the local authorities. The field observations presented here were made in the summer seasons of 1966 and 1967 and later in 1969 during short visits in connection with the supervision of trenching and drilling operations.

### General geology

The geology of Pajala district, in which the Lauttakoski soapstone is located, has been the subject of investigations by a number of geologists (Geijer 1930; Erikson 1954; Ödman 1957; Padget 1970). The Geological Survey of Sweden has recently published an aeromagnetic and geological map over the area in the scale 1:50 000 within its programme of ore deposit investigations in Norrbotten (SGU Ser Af Nr 5-8, 1970).

Bedrock in the immediate surroundings of soapstone include metamorphosed sedimentary, volcanic and igneous intrusive rocks of Pre-Cambrian age. The geological map (Plate 1) shows the distribution of these rocks and the structural features of the area with some modifications with respect to Padget (1970). The sedimentary rocks in the area under discussion consist of quartzite, crystalline limestone, meta-argillite and graphite-rich schist. The volcanic rocks mainly comprise greenstones of basaltic to andesitic composition. The intrusive igneous rocks include soapstone, meta-gabbro, meta-diabase and albitites.

The best established structural features in the area described are the Suinavaara synform and the antiform adjacent to the west. The fold axes plunge to the SE. Faults of both regional and local extent with NW-SE and WNW-ESE trends are recognized. Many zones of strong mylonitization occur and at one place a well developed slickenside has been observed. The displacement in the ruptured zones is rather slight (10-60 m). Rock near the zone of shearing is often intensely altered. The areal distribution of rocks combined with recognition of the main structural features has lead to the following stratigraphical sequence:

Younger	Basic meta-volcanic rocks with graphite-rich schist
	Meta-argillite
	Crystalline limestone
Older	Quartzite

### Description of the country rocks

#### QUARTZITE

Quartzite, which is the oldest known stratigraphical unit in this area, is exposed at three localities along the bank of the river Tarendö. One, c. 1.3 km west-north-west of Suinavaara is closely associated with crystalline limestone. The second locality occurs c. 2 km north-north-west of Suinavaara where quartzite outcrops on both banks of the river and is jointed and much tectonized. Practically no primary sedimentary structure is discernable. The third locality is c. 1.2 km north-east of Suinavaara. The quartzite even here is jointed and completely recrystallized.

The thickness of quartzite as observed does not exceed 50 m. The rock is composed of over 98 % of quartz. Nearly all of the quartz grains show serrated grain boundaries and undulatory extinction. The main accessory minerals are muscovite and feldspar, the later generally albitic. Hematite, magnetite, apatite and zircon also occur.

#### CRYSTALLINE LIMESTONE

The crystalline limestone is exposed only at one locality, namely near the quartzite c. 1.3 km west-north-west of Suinavaara. It is generally impure and yellowish grey in colour, the purer parts showing a somewhat reddish tinge. It is poorly exposed and the bedding is indistinct. It is impossible to ascertain its stratigraphical relationship in respect to the quartzite which it probably overlies. X-ray determinations showed the dominant carbonate mineral to be calcite. Dolomite is present in small amounts generally around 5 %. Many large and small irregular quartzitic inclusions are observed in the limestone. Its chemical composition is shown in Table 1.

**TABLE 1. A<sub>1</sub>. Chemical and modal analyses of crystalline limestone, Kalkipahta, Lauttakoski.**

Weight %		Cation numbers	Mode (764 points)	
SiO <sub>2</sub>	20,2	336	Carbonate	75 %
TiO <sub>2</sub>	0.2	3	Quartz	20 %
Al <sub>2</sub> O <sub>3</sub>	0.3	3	Muscovite, talc	5 %
Fe <sub>2</sub> O <sub>3</sub>	0.1	1		100 %
FeO	0.2	3		
MnO	0.04	1		
CaO	41.8	745		
MgO	1.1	27		
Na <sub>2</sub> O	0.1	2		
K <sub>2</sub> O	0.3	3		
H <sub>2</sub> O <sup>+</sup>	1.8	100		
H <sub>2</sub> O <sup>-</sup>	0.2	11		
CO <sub>2</sub>	34.3	779		
Total	100.64			

In thin section the carbonate grains exhibit beautiful examples of glide-twinning and in places the twin lamellae are slightly bent. Quartz content of the rock is 10–20 %, occurring partly in the form of drop-shaped grains in the carbonate. These quartz grains show uniform extinction and are rather evenly distributed. Quartz is also observed as fracture fillings. Near the contact towards quartzite, minerals like muscovite, talc, tremolite and chlorite are common.

Of particular interest is the occurrence of zoned carbonate in some thin sections. Such carbonate grains are euhedral while the quartz is anhedral and partly replaces the carbonate. The zoning is due to the presence of some kind of limonitic material. A hydrothermal origin after the tectonic movements seems to be the most probable explanation for this feature.

#### META-ARGILLITE

The meta-argillite is well exposed on the eastern bank of the river Tärendö. It also occurs in the drill-holes made in the unexposed part of the area. This rock occurs above the soapstone and generally between the meta-diorite sills of varying thickness. Mineralogically, the meta-argillite is mainly composed of quartz, biotite, sericite (muscovite) and plagioclase. Magnetite and graphite occur in small amounts. At one exposure the meta-argillite contains considerable graphite. Here the rock is nearly black in colour.

The meta-argillite is often altered into hornfels. The effects of contact metamorphism can be studied in detail. The rock shows more or less progressive

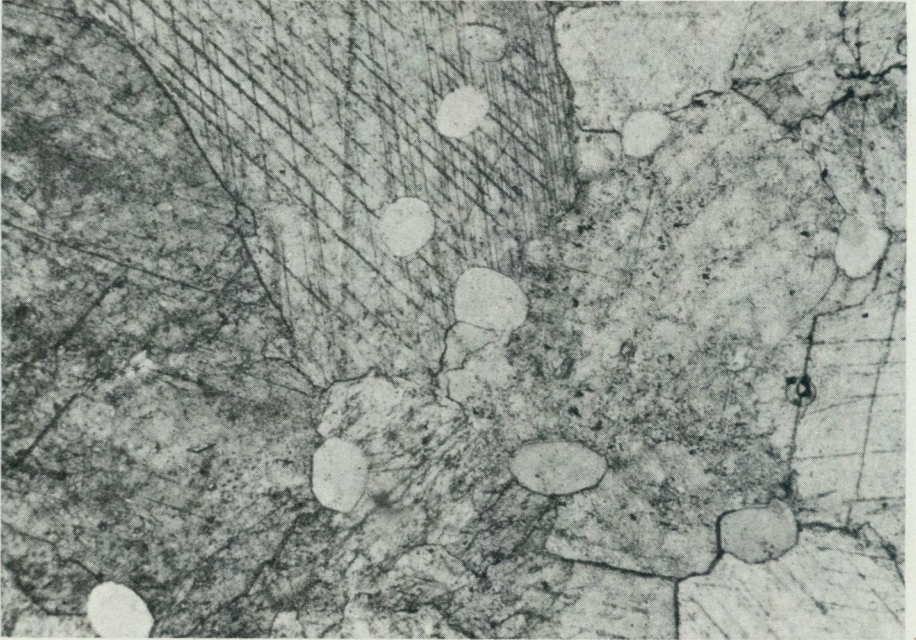


Fig. 1. Drop-shaped grains of quartz in carbonate. Nicols parallel. Magn. 60 x. Sample 20/66 Lauttakoski.



Fig. 2. Zoned carbonate in limestone. Nicols parallel. Magn. 60 x. Sample 27/67 Lauttakoski.

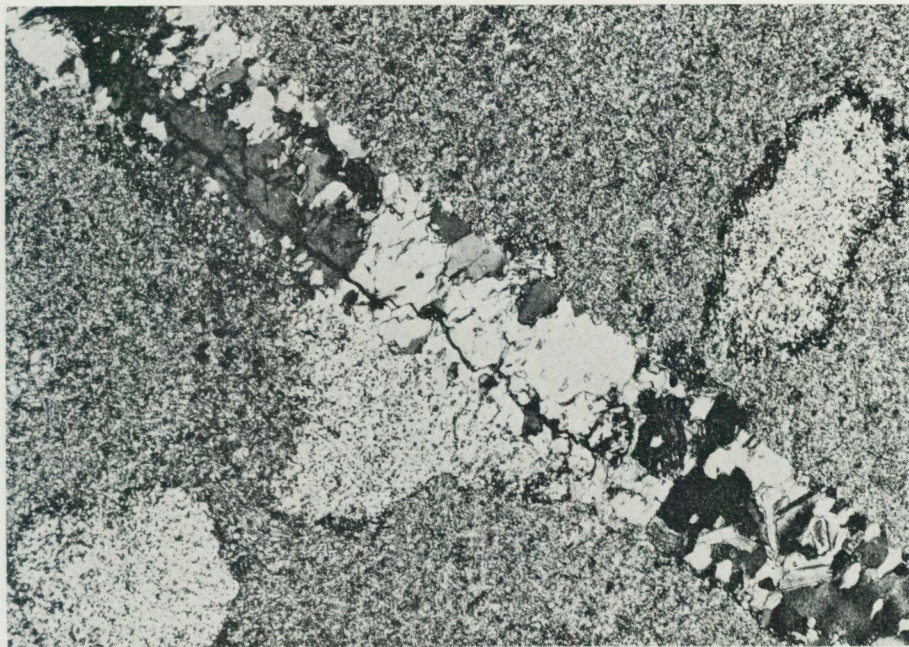


Fig. 3. Cordierite poikiloblasts in meta-argillite. Nicols crossed. Magn. 50 x. Sample 21/66 Lauttakoski.

changes towards the igneous rock. It displays, in the immediate contact, typical hornfelsic texture, consisting of a fine-grained mosaic of equidimensional and unoriented grains. Porphyroblasts of cordierite, crowded with small inclusions of mica, quartz and graphite, appear at a short distance from the igneous rock. Biotite and muscovite, occurring as small knots giving the rock a spotted appearance, are observed to occur at a distance of few metres from the contact. Still further away where the temperature was not sufficient to obliterate the primary structures of the rock, layers, some millimetres to centimetres in thickness can still be seen. The mineral assemblage described above corresponds to the hornblende-hornfels facies of contact metamorphism. The composition of a typical sample of cordierite-bearing meta-argillite is given in Table 2.

#### GRAPHITE-RICH SCHIST

The existence of graphite-rich schist west of the Suinavaara was established when the Johnson Company made an electro-magnetic survey of this area in 1957. This graphite deposit, called Suinavaaragruvan, lies in the lower part of the meta-volcanic sequence. A drill-hole, made in 1958 by the same company near the bank of the river Tärendö, revealed that many graphite-rich layers are present. The total thickness of the graphite-bearing schist is max. 30 m.

**TABLE 2. A<sub>2</sub>. Chemical and modal analyses of cordierite-bearing meta-argillite, Lauttakoski**

Weight %		Cation %	Molecular norms		Niggli numbers	
SiO <sub>2</sub>	61.8	59.3	Salic: Q	23.6	si	231.2
TiO <sub>2</sub>	0.7	0.5	C	8.5	qz	+62.0
Al <sub>2</sub> O <sub>3</sub>	17.5	19.8	Or	32.8	al	38.6
Fe <sub>2</sub> O <sub>3</sub>	1.1	0.8	Ab	10.2	fm	40.5
FeO	4.1	3.2	An	3.2	c	3.6
MnO	0.04			<u>78.3</u>	alk	17.3
CaO	0.9	0.9			mg	0.6
MgO	4.4	6.3	Femic: Hy	16.4	k	0.8
Na <sub>2</sub> O	1.2	2.2	Mt	1.6	ti	2.0
K <sub>2</sub> O	5.5	6.7	Il	1.3	h	22.5
H <sub>2</sub> O <sup>+</sup>	1.8	(11.52)	Ap	0.3	w	0.2
H <sub>2</sub> O <sup>-</sup>	0.5		Fr	0.1	p	0.2
P <sub>2</sub> O <sub>5</sub>	0.12	0.1		<u>19.7</u>	co <sub>2</sub>	0.2
CO <sub>2</sub>	0.03				f <sub>2</sub>	0.4
F	0.08	(0.2)			s	0.1
S	0.01				T	+21.3
Total	99.78	99.8			t	+17.7
			MODE			
Ni	PPM		Main minerals (>25 %):		Quartz, biotite	
Co	20		Essential minerals (5-25 %):		Muscovite, cordierite, plagioclase	
Cr	200		Accessories (<1 %):		Magnetite, graphite	
V	100					

It is distinctly schistose and black to dark brown in colour. According to the analyses, the content of the graphite in the richest parts does not exceed 35 % In addition to the fine-grained graphite, the schist contains varying amounts of biotite, chlorite, albite, quartz, amphibole and sometimes scapolite. Some patches composed mainly of scapolite occur in the schist. Both calcite and pyrite, the later sometimes locally concentrated, are common minor constituents of these schists.

#### BASIC META-VOLCANIC ROCKS

Basic meta-volcanic rocks are well exposed on Suinavaara. Similar rocks have been observed on a hill c. 3 km east of Suinavaara and probably belong to the same stratigraphical unit. These rocks overly the quartzite and meta-argillite. A graphitic schist occurs in the lower parts of the meta-volcanic rocks. They are light to dark green in colour and hence are often called greenstones. Rocks

exposed at Suinavaara are usually fine-grained. In few cases beds very rich in hornblende are somewhat coarser grained. The entire group is clearly of supra-crustal origin. Bedding is visible in few cases in the tuffitic types. Crossbedding has been observed by Padget (1970) at one locality.

Mineralogical examination of these rocks under the microscope reveals that they are made up predominantly of small anhedral to subhedral grains of amphibole and plagioclase. Spene, magnetite and pyrite are the most common accessories. Quartz and carbonate is seen in a few specimens. A microporphyritic texture is not uncommon. Pilotaxitic texture is observed in a specimen from Suinavaara. The amount of amphibole in these rocks varies somewhat but generally makes up more than half of the rock. The amphibole is usually common hornblende, but a pale green actinolitic variety may be present. The hornblende occurs both as a groundmass mineral and as small phenocrysts up to 0.2 mm in diameter. Hornblende also occurs filling fissures and short discordant veins. Plagioclase ( $An_{20-30}$ ) occurs as anhedral grains in the groundmass and as small lath-shaped phenocrysts. The plagioclase phenocrysts are usually less than 0.5 mm in diameter.

As seen from the chemical and modal analyses (Table 3), these rocks show some variation in their composition. Analysis No 3, of a typical dark green sample collected from Suinavaara, corresponds to olivine-andesine-basalt and analysis No 4, of a light green specimen taken from an outcrop near Suinakoski, to andesine-trachybasalt according to the nomenclature of Rittman (1952). A higher sodium content than in basalts (Hess and Poldevaart, 1967) is characteristic for these rocks.

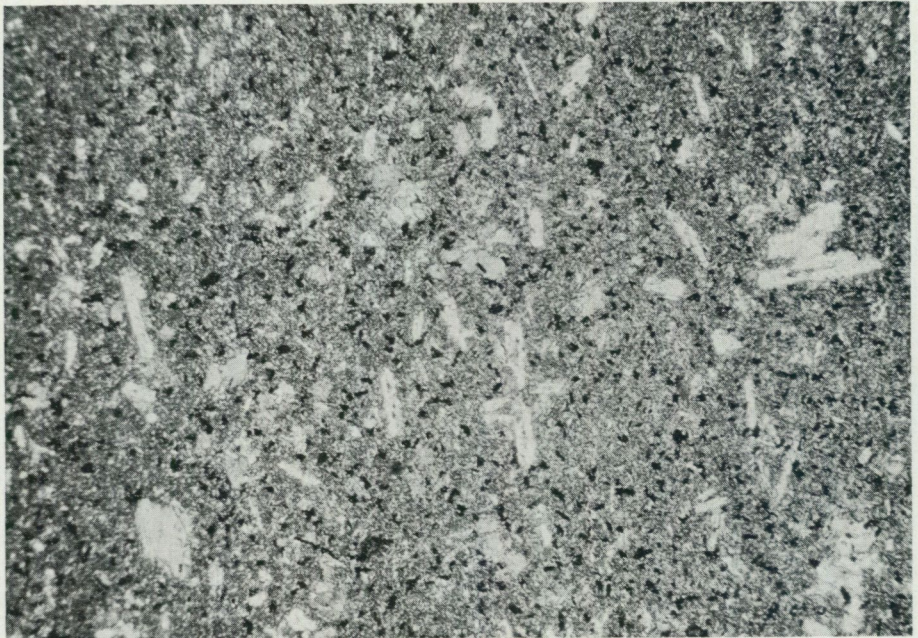


Fig. 4. Pilotaxitic texture in a specimen from Suinavaara. Nicols parallel. Magn. 37 x. Sample 12/69 Lauttakoski.

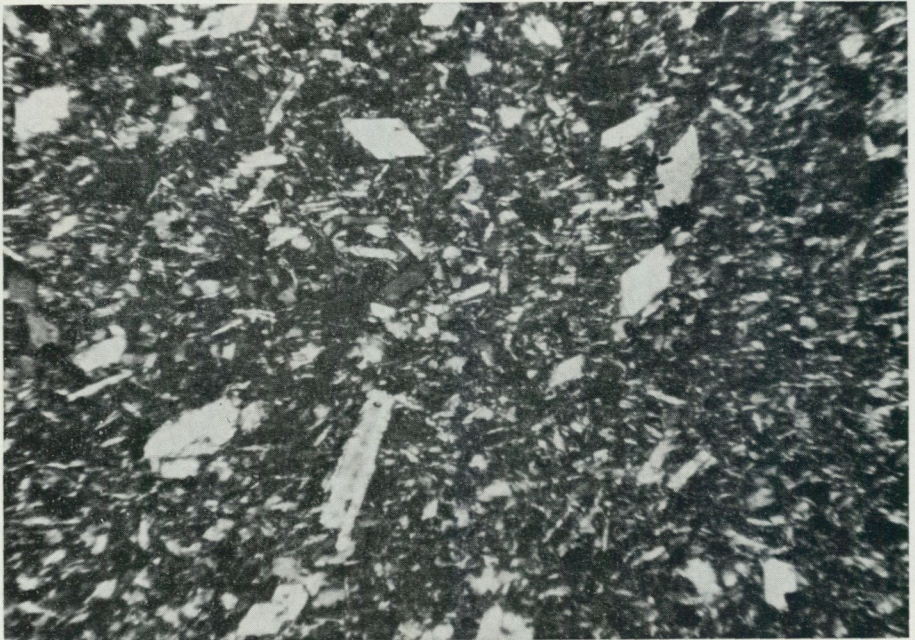


Fig. 5. Phenocrysts of hornblende in a fine-grained matrix. Nicols crossed. Magn. 150 x. Sample 13/67 Lauttakoski.

TABLE 3. Chemical and modal analyses of basic meta-volcanic rocks, Lauttakoski.

A <sub>3</sub> . Basic meta-volcanic, Suinavaara				A <sub>4</sub> . Basic meta-volcanic, Suinakoski									
Weight %		Cation %	Molecular norms	Niggli numbers		Weight %		Cation %	Molecular norms	Niggli numbers			
SiO <sub>2</sub>	49.8	46.8	Salic: Q	—	si	114.8	SiO <sub>2</sub>	54.7	51.4	Salic: Q	3.4	si	141.5
TiO <sub>2</sub>	1.77	1.3	Or	1.2	qz	-18.4	TiO <sub>2</sub>	1.48	1.0	Or	7.0	qz	-3.9
Al <sub>2</sub> O <sub>3</sub>	13.8	15.3	Ab	30.5	al	18.7	Al <sub>2</sub> O <sub>3</sub>	11.5	12.7	Ab	31.0	al	17.6
Fe <sub>2</sub> O <sub>3</sub>	1.3	0.9	An	<u>20.9</u>	fm	51.8	Fe <sub>2</sub> O <sub>3</sub>	3.5	2.5	An	<u>11.1</u>	fm	53.3
FeO	11.8	9.3		<u>52.6</u>	c	21.2	FeO	9.6	7.5		<u>52.5</u>	c	17.7
MnO	0.2	0.2	Femic: Di	17.2	alk	8.3	MnO	0.09	0.7	Femic: Di	16.0	alk	11.4
CaO	8.6	8.7	Hy	9.3	mg	0.5	CaO	6.4	6.4	Hy	22.1	mg	0.5
MgO	7.7	10.8	Ol	14.3	ti	3.0	MgO	6.6	9.2	Mt	5.0	k	0.2
Na <sub>2</sub> O	3.6	6.6	Mt	1.9	h	8.2	Na <sub>2</sub> O	3.7	6.7	Il	2.8	ti	2.8
K <sub>2</sub> O	0.2	0.2	Il	3.4	w	0.1	K <sub>2</sub> O	1.2	1.4	Pr	0.2	h	9.8
H <sub>2</sub> O+	1.06	(6.6)	Fr	<u>0.3</u>	f <sub>2</sub>	0.5	H <sub>2</sub> O+	1.14	(7.14)	Cc	<u>0.3</u>	w	0.2
H <sub>2</sub> O-	0.05			46.4	T	+10.4	H <sub>2</sub> O-	0.05			46.4	co <sub>2</sub>	0.5
CO <sub>2</sub>	<0.01				t	-10.8	CO <sub>2</sub>	0.12	0.2			f <sub>2</sub>	0.1
F	0.13	(0.4)					F	0.02	(0.1)			s	0.5
S	0.01						S	0.1	(0.1)			T	+6.2
												t	+11.5
Total	100.02	100.1					Total	100.20	99.7				
PPM			MODE				PPM			MODE			
Ni	200		Main minerals:	Hornblende, plagioclase (An <sub>27</sub> )			Ni	260		Main minerals:	Hornblende, plagioclase (An <sub>20-30</sub> )		
Co	90		(>25 %)				Co	120		(>25 %)			
Cr	450		Accessories:	Sphene, magnetite, pyrite			Cr	600		Subordinate minerals:	Quartz (1-5 %)		
V	1100		(<1 %)				V	900		Accessories:	Calcite, magnetite, sphene, pyrite (<1 %)		

## BASIC INTRUSIVE ROCKS

Intrusive rocks of basic composition are exposed at many localities especially along the banks of the river Tärendö. They make up a large body of gabbro which together with albitites occupies more than half of the area described here. Basic rocks also occur close to the soapstone and in the drill-holes, where they appear as sills of varying thickness at different levels. The distribution of these rocks on the geological map (Plate 1) is marked partly on the basis of outcrops and data from the various drillholes and partly on the results of the ground magnetic and aeromagnetic measurements.

Basic intrusive rocks at Lauttakoski vary somewhat in appearance from place to place, but most of them are dark green and medium-grained. The few contacts observed, especially those towards meta-argillite exhibit chilled margins indicating a marked temperature difference at the time of intrusion. It appears that these basic rocks are somewhat younger than soapstone, a few contacts between basic sills and soapstone suggesting this relationship. The contacts are generally sharp and at some places a few centimetres thick chlorite-vermiculite-rich contact zone is developed.

The mineralogical composition of these rocks varies. However rocks composed of mainly hornblende-chlorite-albite, augite-hornblende-oligoclase, hornblende-biotite-albite are the most common. Rarely the mineral association augite-hornblende-andesine is also met with. No clear-cut boundary can be drawn between the occurrence of various rock-types. The texture of these rocks is mainly intersertal, occasionally hypidiomorphic. The plagioclase occurs generally as lath-shaped well-twinned crystals, rarely zoned. Hydrothermal alteration of the minerals is common. Plagioclase in some thin sections is strongly saussuritized while in others, despite an intense alteration of the ferromagnesian minerals, it is entirely fresh or only partially altered. The composition of the plagioclase was determined by measurement of the maximum extinction angle in symmetric sections and by comparing the refractive index with that of the embedding medium (Araldite  $n = 1.54$ ). The plagioclase is predominantly albite-oligoclase, andesine being only occasionally present.

The augite ( $2V\gamma = 56^\circ-58^\circ$  and  $cAZ = 37^\circ$ ) shows weak pleochroism in thin sections and is often fully uralitized to hornblende. The hornblende present in the basic intrusive rocks is generally green with distinct pleochroism,  $2Va = 66^\circ$  and  $cA\gamma = 21^\circ$ . In a few cases a nearly colourless amphibole with weak pleochroism is present. The biotite is brown, strongly pleochroic and frequently contains pleochroic haloes. It is often chloritized. Chlorite is observed as pseudomorphs after hornblende and biotite and shows a positive elongation. The major opaque mineral is magnetite, the general content being 3-8 %; however higher and lower concentrations occur locally. Other opaque minerals are ilmenite, pyrrhotite and pyrite. Carbonate, apatite and rutile are common accessory minerals.



Fig. 6. Intersertal texture in meta-diabase. Nicols crossed. Magn. 30 x. Sample 40/69 Lauttakoski.

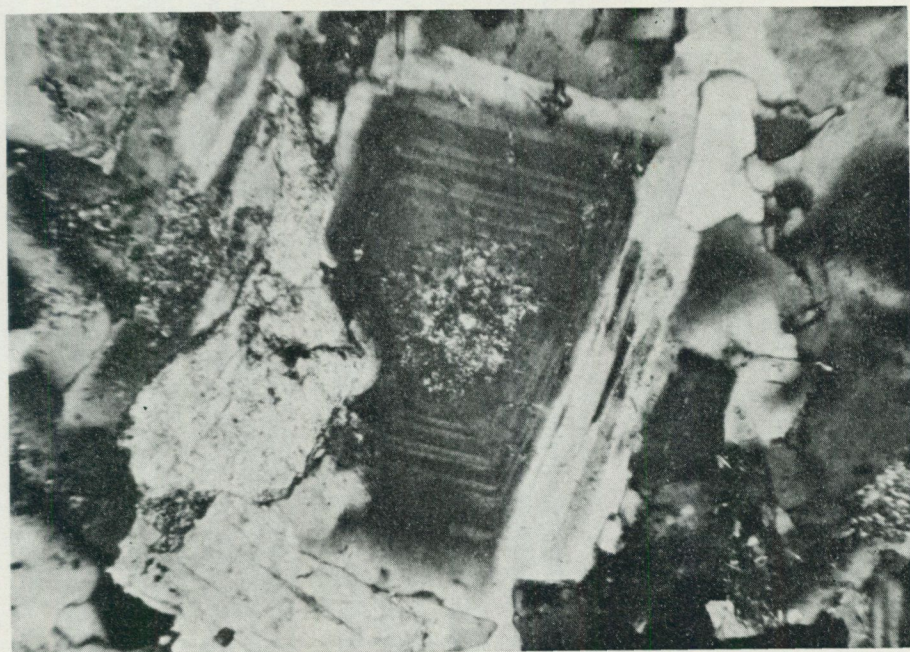


Fig. 7 Zoned plagioclase in meta-gabbro. Nicols crossed. Magn. 150 x. Sample 11/67 Lauttakoski.

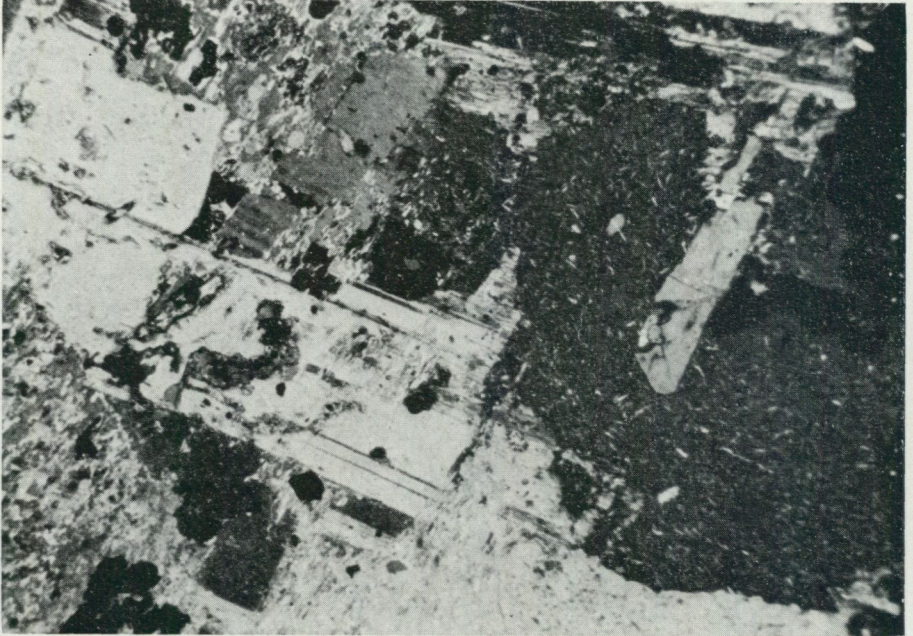


Fig. 8. Scapolite (dark) partially replacing plagioclase in meta-diabase. Nicols crossed. Magn. 37 x. Sample 16/66 Lauttakoski.

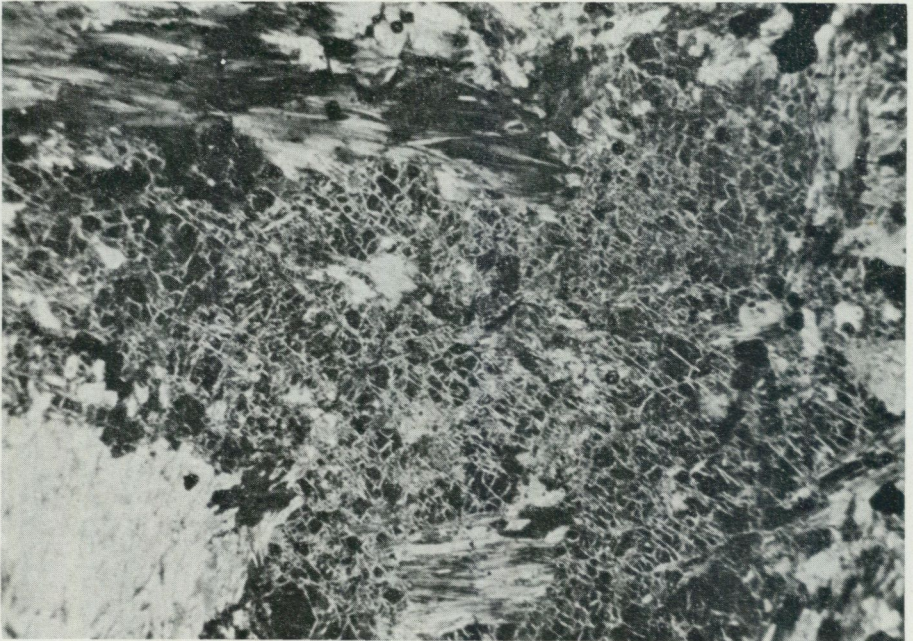


Fig. 9. Fractured grains of scapolite in meta-diabase. Nicols crossed. Magn. 37 x. Sample 24/67 Lauttakoski.

Scapolite is not uncommon in the basic intrusive rocks. However it is found to be more common along the shearing and contact zones where it is often accompanied by carbonate. Scapolite in these rocks occurs mainly as anhedral grains which partially or completely replace the plagioclase. Large grains of scapolite are full of minute inclusions. The refractive indices ( $n_{\omega} = 1.575$ ;  $n_{\epsilon} = 1.550$ ) of scapolite from a scapolite-rich meta-gabbro suggest that it is a mizzonite with a composition around  $Ma_{45} Me_{55}$ . Scapolitization in the area described in this paper is not of regional character. The only rock-type, apart from the basic intrusives, which contains scapolite is the graphitic schist. Scapolitization is apparently caused by carbonate-bearing, hydrothermal solutions involved in the process of carbonatization.

Studies of basic sills occurring at various levels and that of the samples collected from the main body of gabbro did not reveal any systematic differences in their mineralogy, or in their degree of alteration. Certain parts especially those along the rupture zones are intensely altered. Carbonatization and scapolitization is common in such parts. Basic sills near the contact towards the soapstone contain much more hornblende and far less plagioclase than the normal types.

Two chemical analyses of basic intrusive rocks are presented in Table 4. One is of the most common dark green type, taken from the largest outcrop on the eastern bank of the river Tärendö, where the rock occurs as a sill between the soapstone and meta-argillite. The other analysis is of a sample taken from an outcrop situated c. 1.4 km north-east of Suinavaara, close to the albitites and belonging to the main body of gabbro.

#### ALBITITES

Albitites are exposed at several places along the banks of the river Tärendö. These rocks, as seen from the geological map (Plate 1), occur partly as a large body and partly as small concordant or discordant intrusions. Their colour varies from reddish grey to light greyish brown depending upon the presence or absence of biotite, chlorite and carbonate. Grain size is generally 0.5–2 mm, but some parts near the contact towards quartzites are fine-grained. Contacts of albitites with other rock-types are nowhere exposed. Many outcrops along the banks of the river can only be studied in late summer when the water-level is low.

The rocks described here as albitites are not of homogenous composition. Many varieties are present but all of them are characterized by high content of albite and a low content of dark minerals. Rocks composed solely of albite have not been observed and the albite content varies from 70–86%. Three varieties of albitites, namely chlorite-biotite-rich, carbonate-rich and quartz-

TABLE 4. Chemical and modal analyses of basic intrusive rocks, Lauttakoski.

A <sub>3</sub> . Meta-dabase, Tärendö river					A <sub>6</sub> . Meta-gabbro, 1 km NW Suinavaara								
Weight %		Cation %	Modcular norms		Niggli numbers		Weight %		Cation %	Molecular norms		Niggli numbers	
SiO <sub>2</sub>	49.8	47.6	Salic: Q	4.9	si	116.8	SiO <sub>2</sub>	55.9	52.1	Salic: Q	5.9	si	156.0
TiO <sub>2</sub>	2.5	1.8	Or	1.8	qz	+2.0	TiO <sub>2</sub>	0.79	0.6	Or	10.7	qz	-56.0
Al <sub>2</sub> O <sub>3</sub>	11.5	13.0	Ab	25.5	al	15.9	Al <sub>2</sub> O <sub>3</sub>	17.0	18.7	Ab	30.6	al	28.0
Fe <sub>2</sub> O <sub>3</sub>	6.7	4.8	An	<u>17.1</u>	fm	64.1	Fe <sub>2</sub> O <sub>3</sub>	2.4	1.7	An	<u>25.0</u>	fm	37.3
FeO	8.2	6.6		<u>49.3</u>	c	12.8	FeO	4.6	3.6		<u>72.2</u>	c	21.8
MnO	0.05		Femic: Di	4.5	alk	7.2	MnO	0.11	0.1	Femic: Di	6.5	alk	13.0
CaO	5.1	5.2	Hy	29.0	mg	0.6	CaO	7.3	7.3	Hy	14.4	mg	0.6
MgO	10.3	14.7	Mt	9.8	k	0.1	MgO	4.9	6.8	Mt	3.5	k	0.2
Na <sub>2</sub> O	3.0	5.6	Il	4.8	ti	4.4	Na <sub>2</sub> O	3.6	6.5	Il	1.5	ti	0.2
K <sub>2</sub> O	0.3	0.4	Ap	0.4	h	13.2	K <sub>2</sub> O	1.8	2.1	Ap	0.6	h	5.5
H <sub>2</sub> O <sup>+</sup>	1.7	(10.8)	Fr	0.1	w	0.4	H <sub>2</sub> O <sup>+</sup>	0.6	(3.7)	Fr	0.1	w	0.3
H <sub>2</sub> O <sup>-</sup>	0.4		Pr	0.1	p	0.1	H <sub>2</sub> O <sup>-</sup>	0.2		Cc	<u>0.6</u>	p	0.2
P <sub>2</sub> O <sub>5</sub>	0.17	0.1	Cc	<u>0.6</u>	co <sub>2</sub>	0.7	P <sub>2</sub> O <sub>5</sub>	0.24	0.2		<u>27.2</u>	co <sub>2</sub>	0.8
CO <sub>2</sub>	0.2	0.3		<u>49.3</u>	f <sub>2</sub>	0.2	CO <sub>2</sub>	0.24	0.3			f <sub>2</sub>	0.5
F	0.06	(0.2)			s	0.3	F	0.06	(0.2)			s	0.2
S	0.05	(0.1)			T	+8.7	S	0.02				T	+15.0
					t	-4.1						t	+3.2
Total	100.03	100.1					Total	99.76	100.0				
PPM			MODE (1463 points)				PPM			MODE (1647 points)			
Ni	150		Plagioclase (An <sub>20-30</sub> )		40.2 %	Ni	60		Plagioclase (An <sub>35-50</sub> )		60.2 %		
Co	45		Hornblende (uralitic)		28.3 %	Co	40		Augite		16.8 %		
Cr	120		Augite		15.4 %	Cr	60		Hornblende (uralitic)		7.6 %		
V	350		Scapolite (Ma <sub>45</sub> Me <sub>35</sub> )		6.8 %	V	200		Biotite		7.4 %		
			Biotite		5.8 %				Chlorite		2.3 %		
			Opaque		3.3 %				Carbonate		1.2 %		
			Apatite, sphene		0.2 %				Opaque, apatite		4.5 %		
					<u>100.0 %</u>						<u>100.0 %</u>		

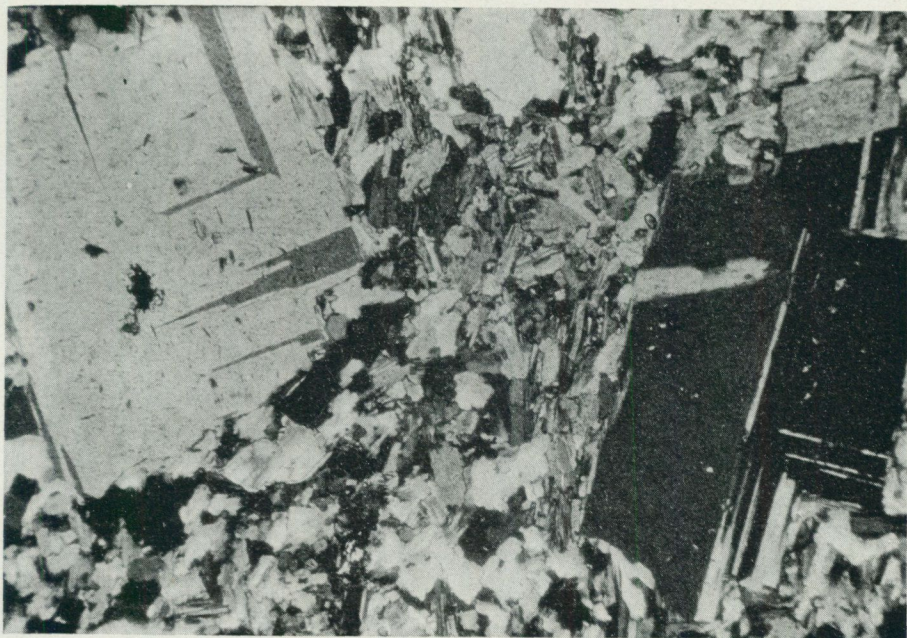


Fig. 10. Porphyritic texture in quartz-rich albitite; albite phenocrysts in a fine-grained matrix of albite and quartz. Nicols crossed. Magn. 37 x. Sample 2/70 Lauttakoski.



Fig. 11 Intersertal texture in carbonate-rich albitite; albite crystals practically unaltered with interstitial carbonate. Nicols crossed. Magn. 37 x. Sample 16/67 Lauttakoski.

rich are common, the first mentioned being the most abundant. The minerals chlorite, biotite and carbonate often give these rocks a patchy appearance. The chlorite-biotite-rich albitites under the microscope show typical intersertal textures. The albite laths, usually 2–3 mm in size are randomly orientated and often saussuritized. Most of the biotite occurs as large subhedral grains between the albite individuals. The chlorite is found to be mainly an alteration product of the biotite.

In quartz-rich albitites a porphyritic texture is common. Phenocrysts of albite, on average 2 mm long occur in a fine-grained matrix composed mainly of albite and quartz. The albite in this variety of albitites is practically unaltered. The anhedral quartz grains display undulatory extinction.

The carbonate-rich albitites also show an intersertal texture. The carbonate grains are usually anhedral and occur mainly interstitially between the albite crystals. Carbonate grains filling the fissures are subhedral. The most common carbonate mineral is dolomite with subordinate amounts of calcite. The accessory minerals present in the different varieties of albitites are magnetite, hematite, ilmenite, rutile and in some cases amphibole.

Albitites and albite diabases, sometimes called leuco-diabases, have been described by a number of authors from various parts of the world. Different views have been put forward about the genesis of these rocks. Some authors consider them to be metasomatic rocks while others prefer a magmatic origin. This topic has attracted the attention of many prominent Fennoscandian geologists. Those who have discussed this problem recently are, e. g. Gjelsvik 1958; Padget 1959; Meriläinen 1961; Frietsch 1966; and Nuutilainen 1968. The intersertal and porphyritic texture in the albitites at Lauttakoski suggest their primary magmatic character. Albitites are closely associated with the basic intrusive rocks and most probably represent an acid differentiate of them. Chemical and modal analyses of the three most common varieties of albitites present at Lauttakoski are given in Table 5.

**TABLE 5. Chemical and modal analyses of albitites, Lauttakoski.**

A <sub>7</sub> . Chlorite-biotite-rich albitite				A <sub>8</sub> . Carbonate-rich albitite								
Weight %	Cation %	Molecular norms	Niggli numbers*)	Weight %	Cation %	Molecular norms	Niggli numbers*)					
SiO <sub>2</sub>	58.9	Salic: Q	5.4	si	200.4	SiO <sub>2</sub>	52.7	45.8	Salic: Q	5.0	si	287.5
TiO <sub>2</sub>	0.66	C	4.2	qz	-8.6	TiO <sub>2</sub>	0.7	0.5	C	2.1	qz	+17.1
Al <sub>2</sub> O <sub>3</sub>	18.8	Or	3.5	al	37.8	Al <sub>2</sub> O <sub>3</sub>	15.3	15.7	Or	0.6	al	49.2
Fe <sub>2</sub> O <sub>3</sub>	3.7	Ab	65.7	fm	31.1	Fe <sub>2</sub> O <sub>3</sub>	0.4	0.3	Ab	<u>67.4</u>	fm	8.2
FeO	2.8	An	<u>3.1</u>	c	4.1	FeO	1.5	1.1		<u>75.1</u>	alk	42.6
MnO	0.03		<u>81.9</u>	alk	27.0	MnO	0.07	0.1	Femic: Mt	0.4	ti	2.9
CaO	1.7	Femic: Hy	7.7	mg	0.4	CaO	7.7	7.2	Il	0.9	h	5.6
MgO	2.7	Mt	5.3	ti	1.6	MgO	3.2	4.1	Ap	0.5	w	0.3
Na <sub>2</sub> O	7.8	Il	1.3	h	20.4	Na <sub>2</sub> O	8.0	13.5	Cc	14.3	p	0.7
K <sub>2</sub> O	0.6	Ap	0.8	w	0.5	K <sub>2</sub> O	0.1	0.1	Mg	8.3	T	+6.6
H <sub>2</sub> O+	1.8	Cc	<u>1.2</u>	p	0.4	H <sub>2</sub> O+	0.3	(1.7)	FeCO <sub>3</sub>	<u>0.4</u>	t	+6.6
H <sub>2</sub> O-	0.3		<u>16.3</u>	f <sub>2</sub>	0.6	H <sub>2</sub> O-	0.1			<u>24.8</u>		
P <sub>2</sub> O <sub>5</sub>	0.33			s	0.2	P <sub>2</sub> O <sub>5</sub>	0.29	0.2				
CO <sub>2</sub>	0.48			T	+10.8	CO <sub>2</sub>	9.7	11.5				
F	0.05			t	+6.7	F	<0.01					
S	0.02					S	<0.01					
100.67	Total	100.0		Total	100.06	100.1						
PPM		MODE (1210 points)		PPM		MODE (1495 points)						
Ni	10	Plagioclase (An <sub>4</sub> )	69.5 %	Ni	20	Plagioclase (An <sub>9</sub> )	79.2 %					
Co	15	Chlorite, biotite	16.1 %	Co	10	Carbonate	17.7 %					
Cr	10	Carbonate	1.5 %	Cr	30	Opaque	3.1 %					
V	100	Quartz	8.4 %	V	95		<u>100.0 %</u>					
		Opaque	4.5 %									
			<u>100.0 %</u>									

\*) In calculations of Niggli numbers the CO<sub>2</sub> is omitted as carbonates.

TABLE 5 (continued).

A <sub>9</sub> Quartz-rich albitite					
Weight %		Cation %	Molecular norms		Niggli numbers*
SiO <sub>2</sub>	70.6	63.8	Salic: Q	16.0	si 344.5
TiO <sub>2</sub>	0.22	0.1	C	1.9	qz +69.7
Al <sub>2</sub> O <sub>3</sub>	17.5	18.6	Or	1.2	al 50.4
Fe <sub>2</sub> O <sub>3</sub>	0.1	0.1	Ab	77.5	fm 4.4
FeO	0.2	0.2	An	1.0	c 1.5
MnO	0.01			<u>97.6</u>	alk 43.7
CaO	0.4	0.4	Femic: Hy	1.0	mg 0.7
MgO	0.4	0.5	Il	0.4	ti 0.9
Na <sub>2</sub> O	9.1	15.9	Ap	0.2	h 8.2
K <sub>2</sub> O	0.2	0.2	Cc	0.2	w 0.4
H <sub>2</sub> O <sup>+</sup>	0.5	(3.0)		<u>1.8</u>	T +6.7
H <sub>2</sub> O <sup>-</sup>	0.2				t +5.2
P <sub>2</sub> O <sub>5</sub>	0.07	0.1			
CO <sub>2</sub>	0.08	0.1			
F	<0.01				
S	<0.01				
Total	99.58	100.0			
PPM			MODE (1405 points)		
Ni	5		Plagioclase (An <sub>5</sub> )		81.8 %
Co	5		Quartz		16.9 %
Cr	5		Opaque		1.3 %
V	30				<u>100.0 %</u>

\*) In calculations of Niggli numbers the CO<sub>2</sub> is omitted as carbonates.

### The soapstone deposit

The occurrence of soapstone, as pointed out in the introduction, has been known for a long time. The softness of the rock repeatedly attracted attention in the past and various attempts were made by the inhabitants of the nearby village, Lauttakoski, to use the soapstone. However, quarrying, mainly concentrated to the small exposed part of the occurrence, were not very successful because the soapstone is intensely jointed and contains a large number of carbonate veins and veinlets which made it difficult to obtain pieces suitable for practical purposes. Recently, local authorities invited the Geological Survey to examine the deposit more closely. Up to now only that part of the area

which is adjacent to the exposed part has been investigated. The results, so far indicate that the soapstone occurrence is much larger than earlier thought. They also contribute towards a better understanding of the geology of the area, especially the stratigraphical sequence.

#### MODE OF OCCURRENCE

Some trenches, made during the summer 1967 near the exposed part of the occurrence, revealed that the soapstone probably occurs as a sill-like body in the meta-sediments and is enclosed by the younger meta-diabases. It was further noted that the soapstone is divided into three segments due to tectonic movements. Mineralogical studies on part of the soapstone then known and the associated rock-types showed that the former contains 10–15 % magnetite and the meta-diabases 3–8 % magnetite, while the meta-sediments and basic meta-volcanic rocks are practically free of magnetite. A ground-magnetic survey in the immediate surroundings of the exposed deposit gave a number of anomalies (Fig. 12). In 1969 the southern magnetic anomaly, which runs parallel to the eastern bank of the river Tärendö was selected for drilling, initially because it suggested a possible continuation of the southernmost known segment of the soapstone under the thick glacial till.

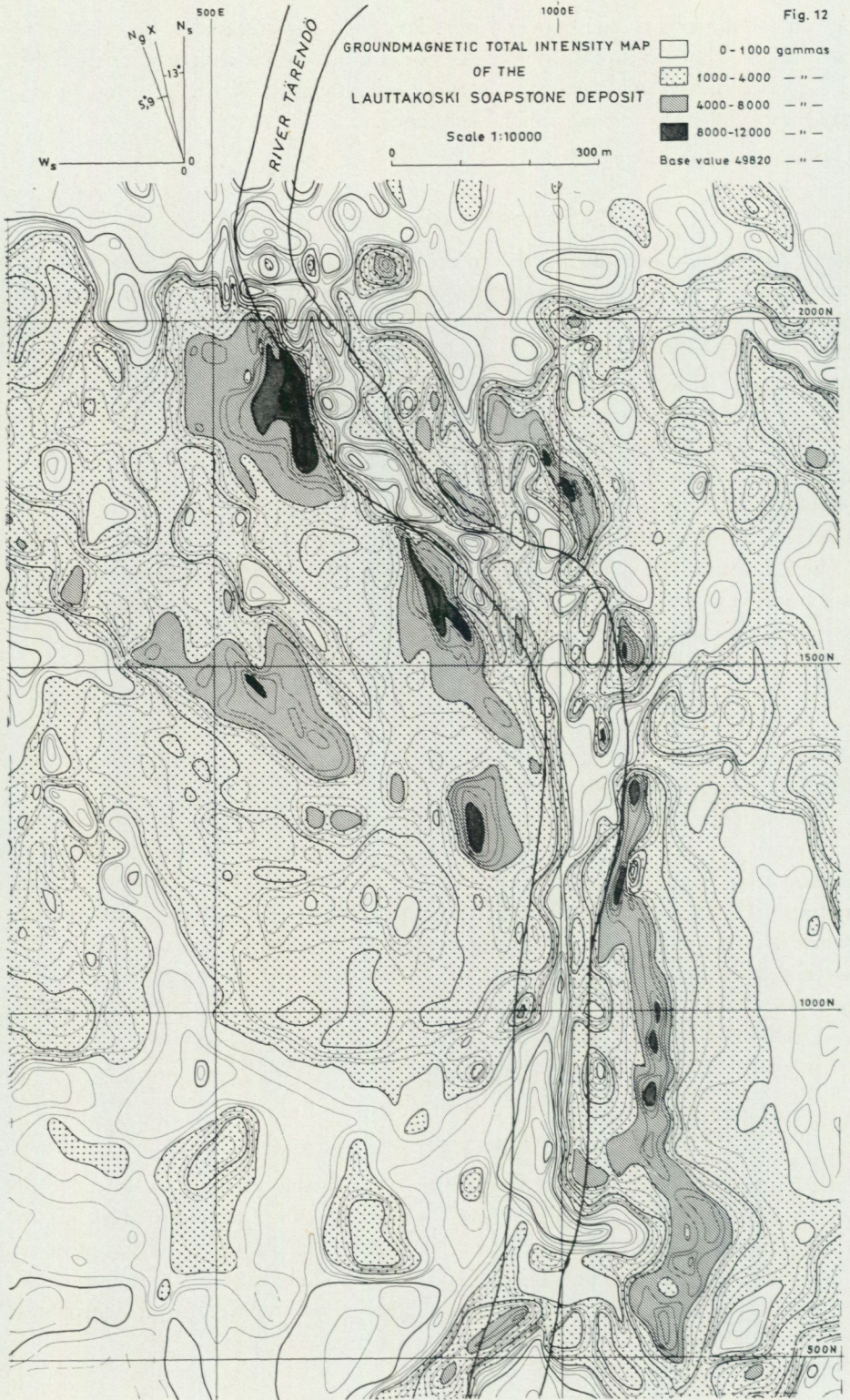
Altogether ten drill-holes were made. The results showed that the soapstone did continue southwards but that a large part of the magnetic anomaly is caused by meta-diabases. The drilling operations confirmed the earlier established mode of occurrence of the soapstone namely that it is an altered sill-like ultramafic body in the meta-sediments.

The soapstone varies in thickness from 40 m to a minimum of a few metres and generally dips c. 45°–75° E. It is not possible at present to say to what extent other magnetic indications in the area are caused by soapstone. Local variations in the magnetite content of the basic intrusive rocks are common and make it difficult to generalize; only further drilling can give a conclusive answer. For the same reason it is too early to estimate the total soapstone reserves at Lauttakoski. However the presently known parts of the deposit contain c. 2 million tons of soapstone if the reserves are calculated down to a depth of 50 m.

#### MINERALOGICAL AND CHEMICAL COMPOSITION

The Lauttakoski soapstone is fine-grained, consisting of a matrix of talc and chlorite (grain size between 50  $\mu$  and 100  $\mu$ ) in which irregular anhedral to subhedral grains and aggregates of other minerals are present. The soapstone varies somewhat in colour but is generally grey to light grey. Parts rich in chlorite display a faint greenish tinge. Megacrysts of amphibole and/or aggregates

Fig. 12



of antigorite thought to represent serpentized olivine at some places give the rock a spotted appearance. While the soapstone is mainly a massive rock, its exposed northern part is markedly schistose (N 30°–35° W/40°–50° NE) and jointed.

The mineralogical composition of the soapstone is dominated by talc, chlorite and carbonate. The content of talc varies from 45–55 % in different parts of the body. Chlorite, the second major constituent, rarely forms less than 20 % of the rock. It is very light green in hand specimen and colourless in thin section. The optical properties determined correspond to clinocllore, the chemical composition determined by X-ray powder methods being  $(\text{Mg}_{4.20}\text{Fe}_{0.74}\text{Al}_{1.06})_6(\text{Si}_{2.94}\text{Al}_{1.06})_4\text{O}_{10}(\text{OH})_8$ . The nature and content of the carbonate minerals is variable. Three carbonate minerals were identified by X-ray powder diffraction methods, dolomite, magnesite and calcite. Dolomite, showing a brownish tinge on the weathered surface, is the most abundant and persistent carbonate. It occurs in the soapstone both as veins and veinlets and as irregular grains. The magnesite and calcite occur generally in small amounts as anhedral to subhedral grains dispersed in the groundmass of talc and chlorite, and occur only locally in considerable quantity. Two carbonate minerals may occur together the one often as porphyroblasts and the other in veinlets. Dolomite and magnesite are more common in the northern and central part while dolomite with some calcite is characteristic of the southern part of the deposit. Carbonate minerals are predominantly a replacement product, largely occurring as fissure fillings. The cross-cutting pattern of veins and veinlets suggest a long period of formation.

The magnetite content of the soapstone is remarkably high, being present in all parts of the deposit and composing between 10–15 weight % of the rock. Magnetite is mainly fine-grained. It occurs as subhedral to anhedral individual grains or in aggregates between the silicate minerals and may contain rounded silicate inclusions. Other opaque minerals include ilmenite which is common and pyrite and pyrrhotite both of which are rare. Amphibole and serpentine occur usually in very small amounts being only occasionally met with as an essential component. Chemical and modal analyses of soapstone from different parts of the deposit are presented in Table 6.

**TABLE 6. Chemical analyses of soapstone, Lauttakoski.**

Analysis No	10		11		12		13	
	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %	Weight %	Cation %
SiO <sub>2</sub> .....	42.1	39.8	37.5	35.1	40.9	38.4	38.0	36.8
TiO <sub>2</sub> .....	0.80	0.6	0.65	0.5	0.82	0.6	0.69	0.5
Al <sub>2</sub> O <sub>3</sub> .....	3.9	4.3	3.2	3.5	4.4	4.9	3.6	4.1
Fe <sub>2</sub> O <sub>3</sub> .....	10.2	7.2	10.3	7.2	9.5	6.7	8.7	6.3
FeO .....	5.1	4.0	7.6	5.9	5.1	4.0	5.4	4.4
MnO .....	0.05		0.14	0.1	0.07	0.1	0.07	0.1
CaO .....	1.5	1.5	0.3	0.3	2.2	2.2	3.1	3.2
MgO .....	27.7	39.0	27.7	38.6	27.6	38.6	28.0	40.4
Na <sub>2</sub> O .....	0.1	0.2	0.2	0.4	0.1	0.2	<0.1	
K <sub>2</sub> O .....	0.2	0.2	0.2	0.2	0.2	0.2	<0.1	
H <sub>2</sub> O+ .....	5.5	(34.7)	5.5	(34.3)	5.2	(32.5)	7.5	(48.5)
H <sub>2</sub> O- .....	0.18		0.2		0.2		0.1	
P <sub>2</sub> O <sub>5</sub> .....	0.13	0.1	0.12	0.1	0.13	0.1	0.07	0.1
CO <sub>2</sub> .....	2.3	3.0	6.3	8.0	3.2	4.1	3.1	4.1
F .....	0.02		0.02		0.02			
S .....	0.02		0.05	(0.1)	0.01		0.07	(0.1)
Total .....	99.80	99.9	99.98	99.9	99.65	100.1	98.40	100.0
		PPM		PPM		PPM		PPM
Ni .....		2000		1600		1600		2000
Co .....		140		80		120		300
Cr .....		800		650		550		1500
V .....		110		100		110		140

**TABLE 6 (continued). Mineralogical composition (weight %) of soapstone calculated on the basis of chemical analyses and X-ray diffraction studies.**

Analysis No	10	11	12	13
Talc .....	56	51	55	45
Chlorite .....	23	21	25	25
Serpentine .....				10
Dolomite .....	3	1	5	5
Calcite .....				3
Magnesite .....	5	12	2	
Magnetite .....	13	15	13	12
Total .....	100	100	100	100

**TABLE 6 (continued).**

Molecular norms

Analysis No	10	11	12	13
Salic: Q .....	1.2	0.7	0.5	
C .....	3.5	2.7	4.0	
Or .....	1.2	1.2	1.2	3.7
Ab .....	0.8	1.7	0.9	
	6.7	6.3	6.6	3.7
Femic: Hy .....	66.4	59.5	65.7	59.1
Ol .....				8.3
Mt .....	14.3	15.0	13.9	12.8
Hm .....	0.4			
Il .....	1.5	1.2	1.6	1.3
Ap .....	0.3	0.3	0.3	0.2
Pr .....		0.1		0.1
Cc .....	2.4	0.3	3.6	5.5
Mg .....	2.4	11.9	3.1	1.5
	87.7	88.3	88.2	88.8

**TABLE 6 (continued).**

Niggli numbers

Analysis No	si	qz	al	fm	c	alk	mg	k	ti	h	w	p	co <sub>2</sub>	f <sub>2</sub>	s	T	t
10	73.3	-28.4	4.0	92.8	2.8	0.4	0.8	0.5	1.0	31.9	0.6	0.1	5.4	0.1	0.1	+3.6	+0.7
11	64.6	-37.5	3.2	95.8	0.5	0.5	0.7	0.4	0.8	31.6	0.5	0.1	14.8	0.1	0.2	+2.7	+2.2
12	70.7	-30.9	4.5	91.1	4.0	0.4	0.8	0.5	1.1	30.0	0.6	0.1	7.6	0.6	0.3	+4.1	
13	65.3	-34.7	3.6	90.7	5.7		0.8		0.9	43.0	0.6		0.7		0.2	+3.6	-2.1

## List of the samples

10. Soapstone from the northern exposed part of the deposit (Loc 4).
11. Soapstone from the middle of the exposed part of the deposit (Loc 13).
12. Soapstone from the southern exposed part of the deposit (Loc 18 19).
13. Soapstone from the unexposed, drilled part of the deposit (Bh 4, sec 9).

## DISCUSSION

The chemical composition of the Lauttakoski soapstone suggests a magnesium-iron-rich and calcium-poor parent ultramafic rock. Niggli numbers and the system of geochemical ranking presented by Brotzen (1966) suggest that

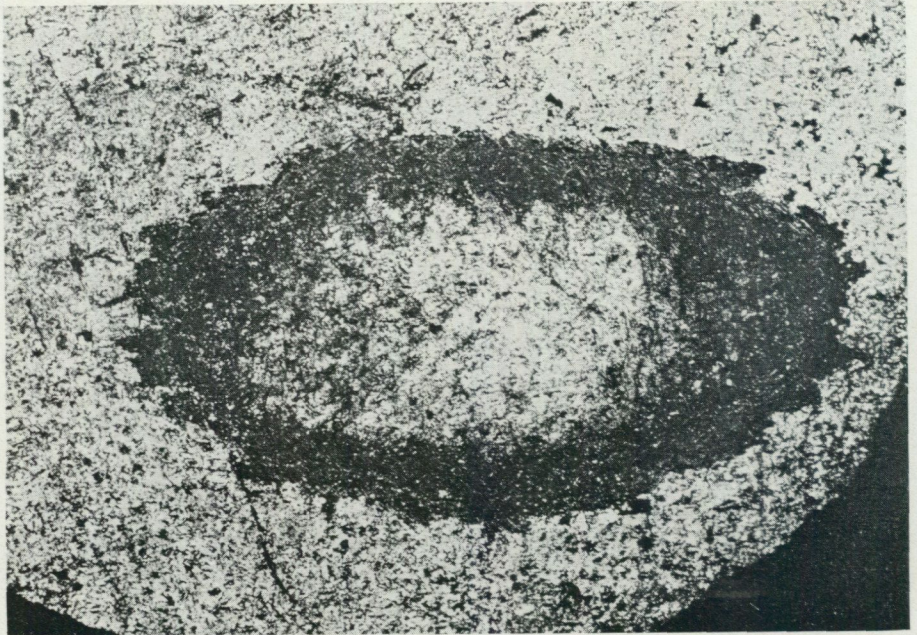


Fig. 13. Altered olivine grain in soapstone. Nicols crossed. Magn. 9 x. Sample 2/65 Lauttakoski.

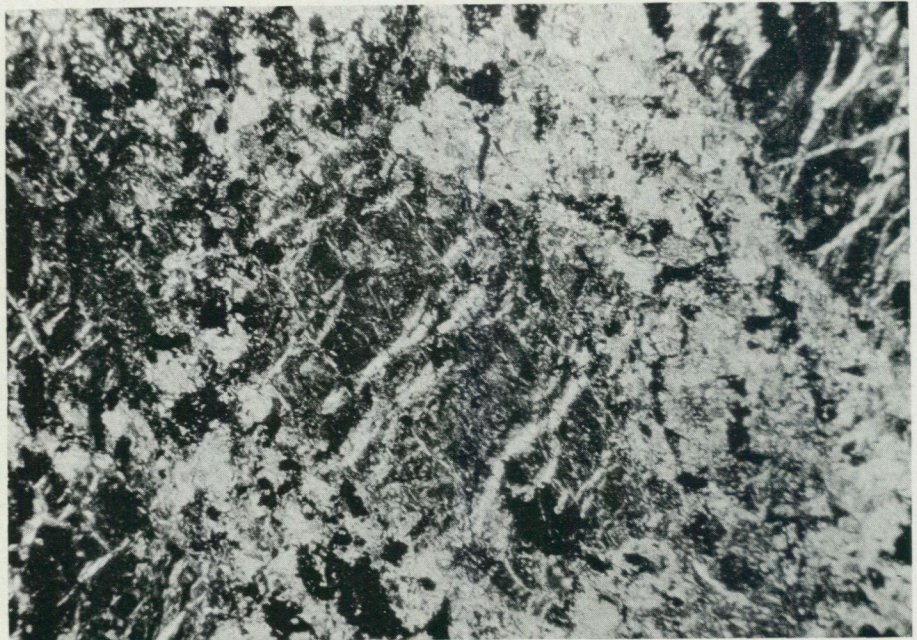


Fig. 14. Carbonatized and steatitized antigorite in soapstone. Nicols crossed. Magn. 37 x. Sample 23/69 Luttakoski.

the parent ultramafic rock could have been a peridotite. The igneous origin of the soapstone is further supported by the high content of nickel, chromium and titanium. Mineralogically the presence of many remnants of antigorite also favour an ultramafic nature of the parent rock of the Lauttakoski soapstone. Antigorite in some cases is seen to be cut by irregular curving fractures often marked by a concentration of fine-grained magnetite – a feature typical of altered olivine. The iron in the soapstone is present mainly as magnetite which is partly relic and partly an alteration product.

It thus seems obvious that the Lauttakoski soapstone is an alteration product of an ultramafic rock. The alternative origin by decarbonatization or silicification of dolomitic beds in the metasediments appears to be excluded by these facts. The antigorite remnants further point towards a serpentinitic mineralogy prior to the formation of talc which implies that the ultramafic rock suffered both serpentinitization and steatitization. The process of steatitization (carbonatization etc) which lead to the formation of soapstone or steatite involve a number of mineralogical and chemical changes. These changes depend mainly upon the initial composition of the ultramafic rock and on the nature of the solutions added to it. Hess (1939) came to the conclusion that soapstone may be formed from ultramafic rocks with a wide range of mineralogical composition. The physico-chemical relations of such alterations has been studied by a number of authors e. g. Bowen and Tuttle 1949; Greenwood 1967.

From the presence of carbonate minerals in the Lauttakoski soapstone it is evident that carbon dioxide was added to the ultramafic rock. The mineralogical composition from different parts of the deposit reveal variations in the degree of carbonatization. Calcite and dolomite, which according to Wiik (1953) indicate a lower degree of carbonatization, are found to be present in the southern part of the deposit while dolomite and magnesite, indicative of a higher degree of carbonatization, are met in the northern part of the deposit. The lower degree of carbonatization in the southern part is also attested by the abundance of relic minerals and by the lower content of talc. It is difficult to separate the carbonates formed at the various stages of alteration of the ultramafic rock. As pointed out earlier in this paper the cross-cutting pattern of carbonate veins and veinlets in the soapstone indicate a long period of formation and that many of these veins are younger than the steatitization. Under the microscope at least two generations of carbonate minerals can be distinguished. The older grains are idioblastic and usually larger in size and always exhibit glide-twinning. The younger grains are xenoblastic, are smaller in size and are not twinned. Some of the younger grains are seen to fill the cracks in the older grains.

Features pointing towards a large increase or decrease in volume during the alteration of the ultramafic body into soapstone are not observed. The formation of soapstone at Lauttakoski may therefore have occurred more or less



Fig. 15. Carbonatized and steatitized amphibole in soapstone. Nicols crossed. Magn. 37 x. Sample 19/69 Lauttakoski.



Fig. 16. Schistose soapstone. Long stretched (dark) aggregates of chlorite. Nicols crossed. Magn. 37 x. Sample 1/66 Lauttakoski.

under constant volume. Pressure and stress played an important role in the alteration. Parts of the soapstone are strongly schistose and jointed and hence were subjected to a considerable differential pressure. Shearing made the ultramafic rock more accessible to the metasomatic alteration. Faults of both regional and local extent occur in the area and may also have been of importance in facilitating the access of solutions and thus the process of steatitization. The solutions responsible for the alteration were most likely derived from the later intrusions of basic rocks as well as from the albitites. Some material necessary for the alteration may also have been provided by the adjacent sediments.

### Conclusion

Mapping, trenching, ground magnetic surveying and exploratory drilling have provided a relatively good picture of the Lauttakoski soapstone deposit, which is an alteration product of an ultramafic intrusion. The latter was emplaced as a sill-like body in the lower parts of a thick section of sedimentary and volcanic rocks probably at an early stage of folding. The contact relationships of the soapstone and basic intrusive rocks which occur as sills enclosing it, suggest that the intrusive rocks are of different age. It is most likely that the emplacement of the basic rocks took place after the intrusion of the ultramafic body. The albitites are the youngest intrusive rocks in the area described in this paper. The close spatial relationship of the various igneous rocks favours the hypothesis that the soapstone represents an ultramafic differentiate related to same magmatism which gave rise to the basic volcanic and intrusive rocks and finally to the albitites.

### Acknowledgements

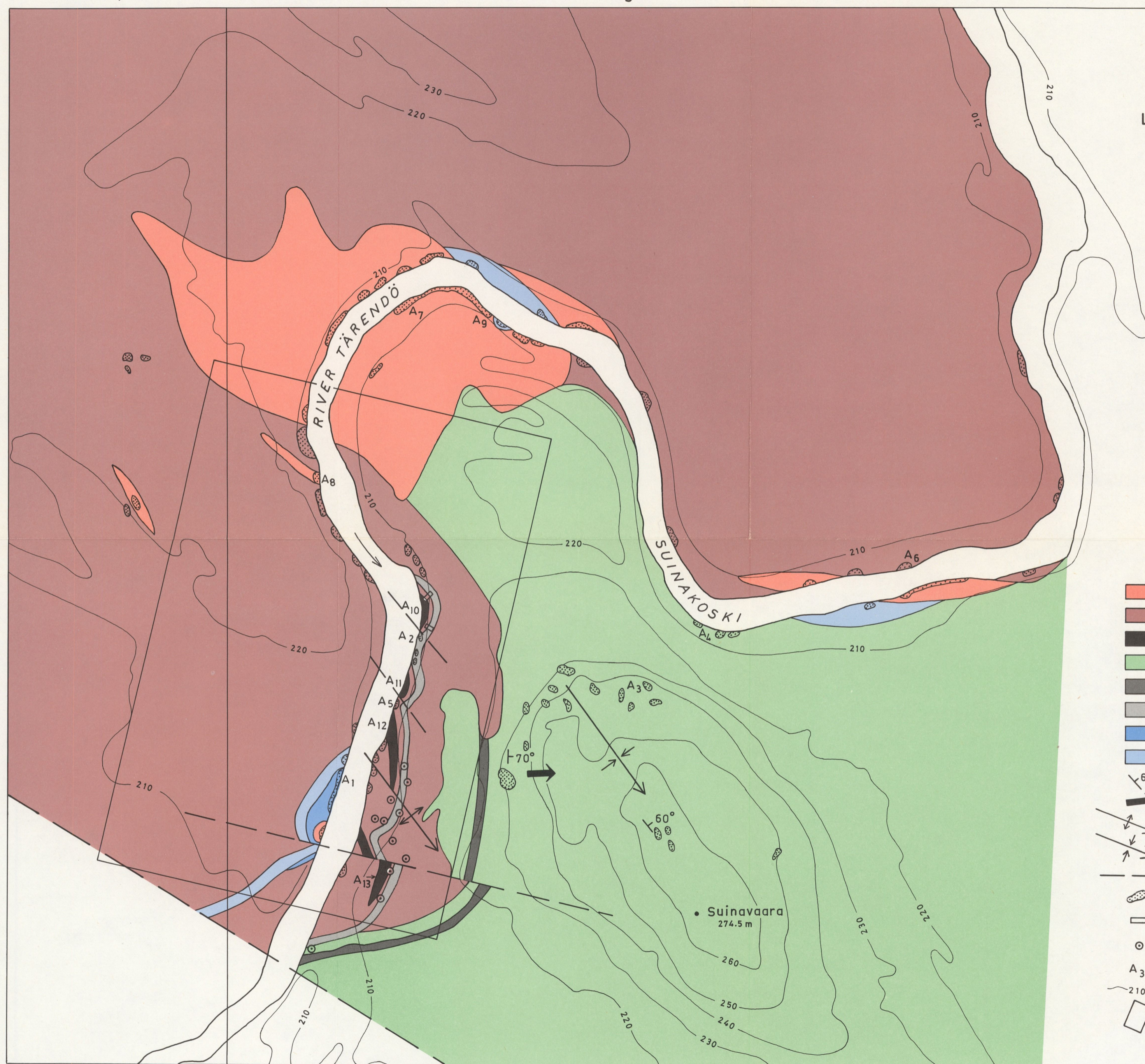
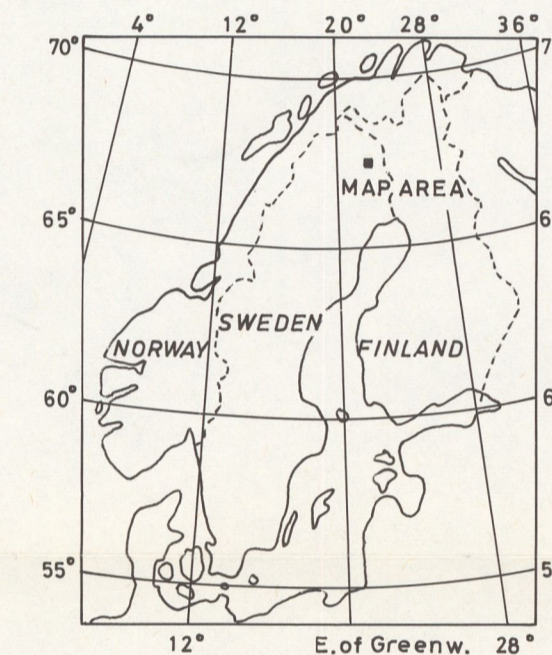
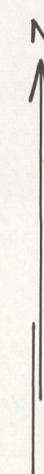
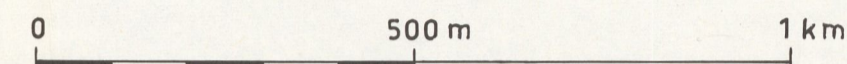
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GEOLOGICAL MAP  
OF THE  
LAUTTAKOSKI SOAPSTONE DEPOSIT  
NORTH SWEDEN  
N.A.SHAIKH, 1972

Scale 1:10 000



- Albitites
- Basic intrusive rocks
- Soapstone
- Basic meta-volcanic rocks
- Graphite-rich schist
- Meta-argillite
- Crystalline limestone
- Quartzite
- Strike and dip
- Way-up determination
- Antiform with plunge of the fold axis
- Synform with plunge of the fold axis
- Fault
- Outcrop
- Trench
- Drill-hole
- Chemical analysis
- Contour interval 10m
- Extent of ground magnetic survey

PRISKLASS E

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